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Pitch Angle Observations of Energetic Particles from the Los Alamos Geostationary Satellites

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A. Abstract

We use here data from the energetic particle detectors (SOPA) on the Los Alamos geostationary satellites. As these satellites do not carry magnetometers, the direction of the magnetic field is synthesized from the particle data, assuming a trapped, gyrotropic particle distribution function.

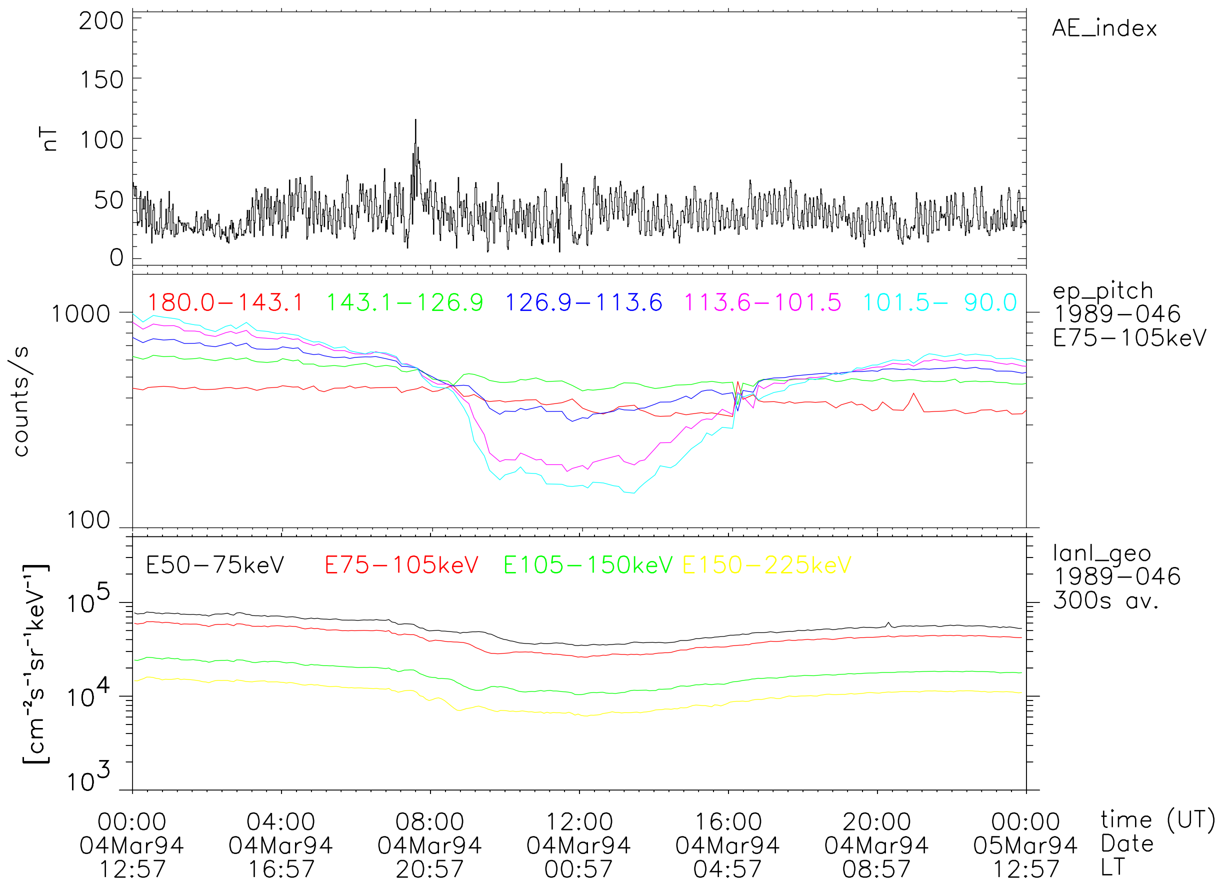
We investigate the pitch angle distributions observed at geosynchronous altitude both inside and outside of the substorm growth and onset regions.

The aim of this study is to investigate the effects of stretched field line regions during substorm growth on the particle distributions that drift through that region.

Any changes of the pitch angle distribution observed can be linked to breaking of the adiabatic invariants in high curvature - ie stretched fields. We intend to use this information to obtain a remote measure of the degree of field line stretching that occurs during the substorm growth phase.

B1. Rationale

Particles drifting through non-dipole magnetic fields such as the Earth's experience drift shell splitting. This leads to individual pitch angles occupying different drift shells. The effects is routinely observed near midnight at geosynchronous orbit:



Here 90^o pitch angle electrons observed near midnight are on drift shells that extend further out on the dayside compared to lower pitch angles. The lower fluxes are due to losses at the magnetopause - the well-known "magnetopause shadowing" effect.

B2. Rationale

Drift shell splitting will occur no matter what the cause of the non-symmetry in the magnetic field. During substorm growth, a stretching of the magnetic field in the midnight region has been observed and linked to the formation of a thin current sheet.

Particles drifting through this growth region will experience localized drift shell splitting. As long as adiabicity is preserved, a given particle distribution entering the stretched region will "stretch out" radially in pitch angle and come back together as the stretched region is exited.

Under very stretched topographies we may expect that field line curvature becomes high enough to break adiabicity. This effect should be first observed by ions, due to their larger gyroradius, but may be seen by electrons under extreme stretching (combination of lower field strength and large curvature of the field line).

Equatorially mirroring particles should not be affected, but any pitch angle range traversing the highly curved portion of a field line may experience some scattering: This would be observed as a loss of particles from that pitch angle range and should be measurable by a satellite positioned after the stretched region (in the direction of particle drift).

C. Satellites / Instrumentation

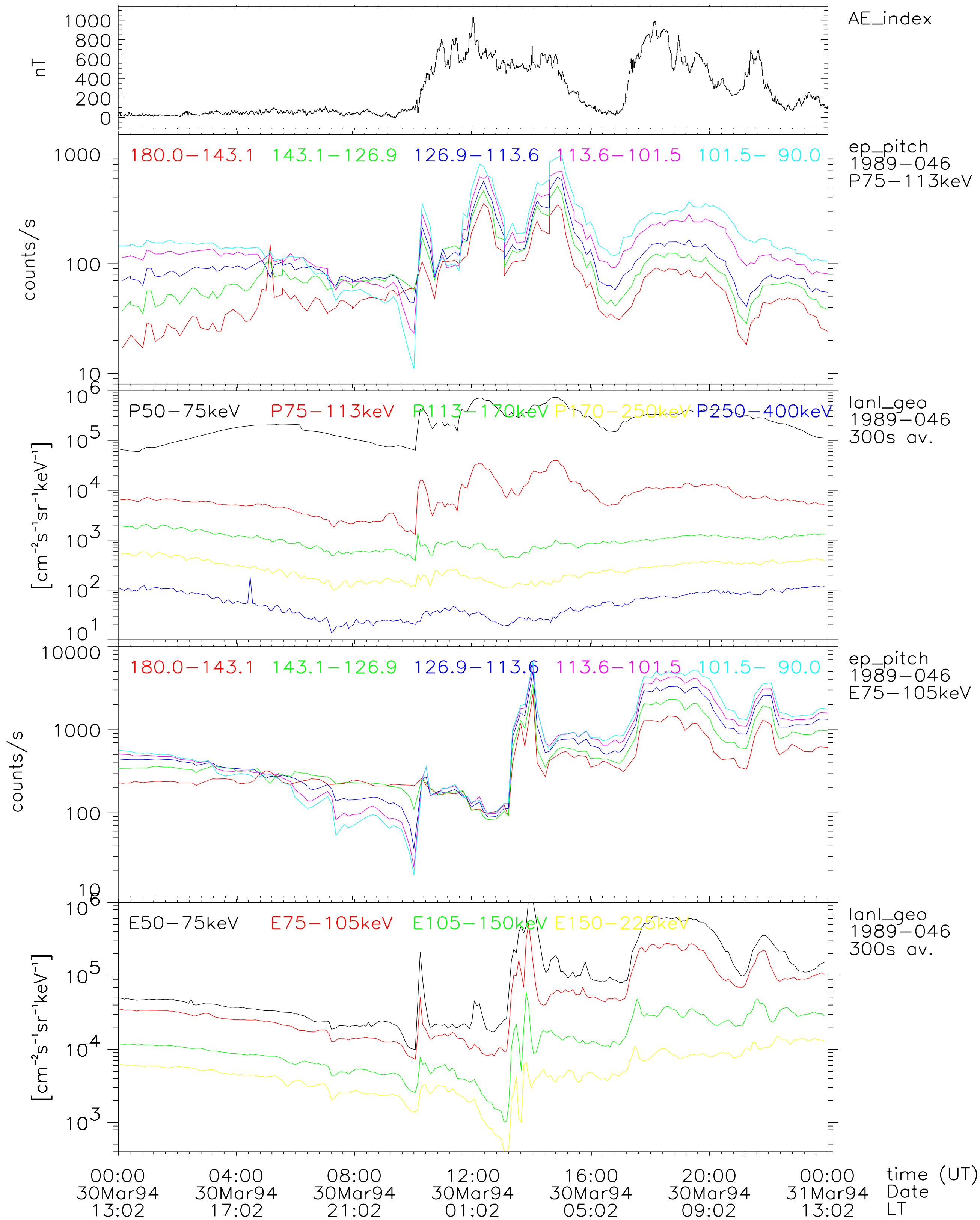
Data comes from the SOPA instrument onboard the LANL geosynchronous satellites. This instrument has three look directions at 30^o, 90^o and 120^o to the spin axis (θ) and we can define 32 azimuthal bins (ϕ).

In the absence of a magnetometer the magnetic field direction is determined from the particle distribution itself. We form the following matrix from the count rate (CR) for 10 minute averages in all θ/ϕ bins:

$$
\begin{aligned}
T_{xx} &= \Sigma_i \Sigma_j (Cr_{ij} \sin\theta_i \cos\phi_j) \sin\theta_i \cos\phi_j && (1)\\
T_{xy} &= \Sigma_i \Sigma_j (Cr_{ij} \sin\theta_i \cos\phi_j) \sin\theta_i \sin\phi_j && (2)\\
T_{xz} &= \Sigma_i \Sigma_j (Cr_{ij} \sin\theta_i \cos\phi_j) \cos\theta_i && (3)\\
T_{yy} &= \Sigma_i \Sigma_j (Cr_{ij} \sin\theta_i \cos\phi_j) \sin\theta_i \sin\phi_j && (4)\\
T_{yx} &= \Sigma_i \Sigma_j (Cr_{ij} \sin\theta_i \cos\phi_j) \cos\theta_i && (5)\\
T_{yz} &= \Sigma_i \Sigma_j (Cr_{ij} \cos\theta_i) \cos\theta_i && (6)
\end{aligned}
$$

Under the assumption of isotropy we diagonalize this matrix to find three eigenvalues/vectors. We choose the direction of B to be equal to the eigenvector corresponding to the most unique eigenvalue.

D1 Inside substorm growth region pitch angle data



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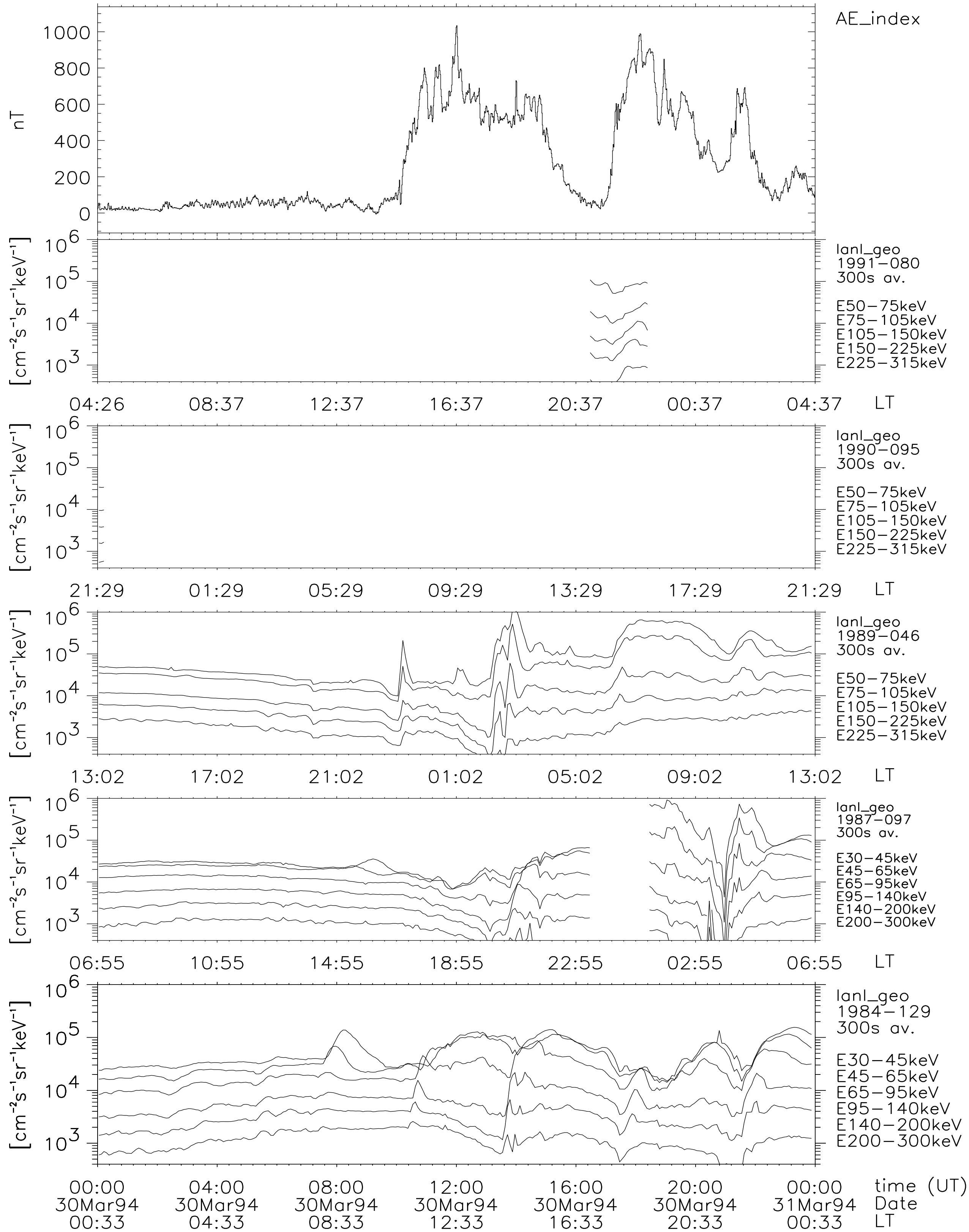
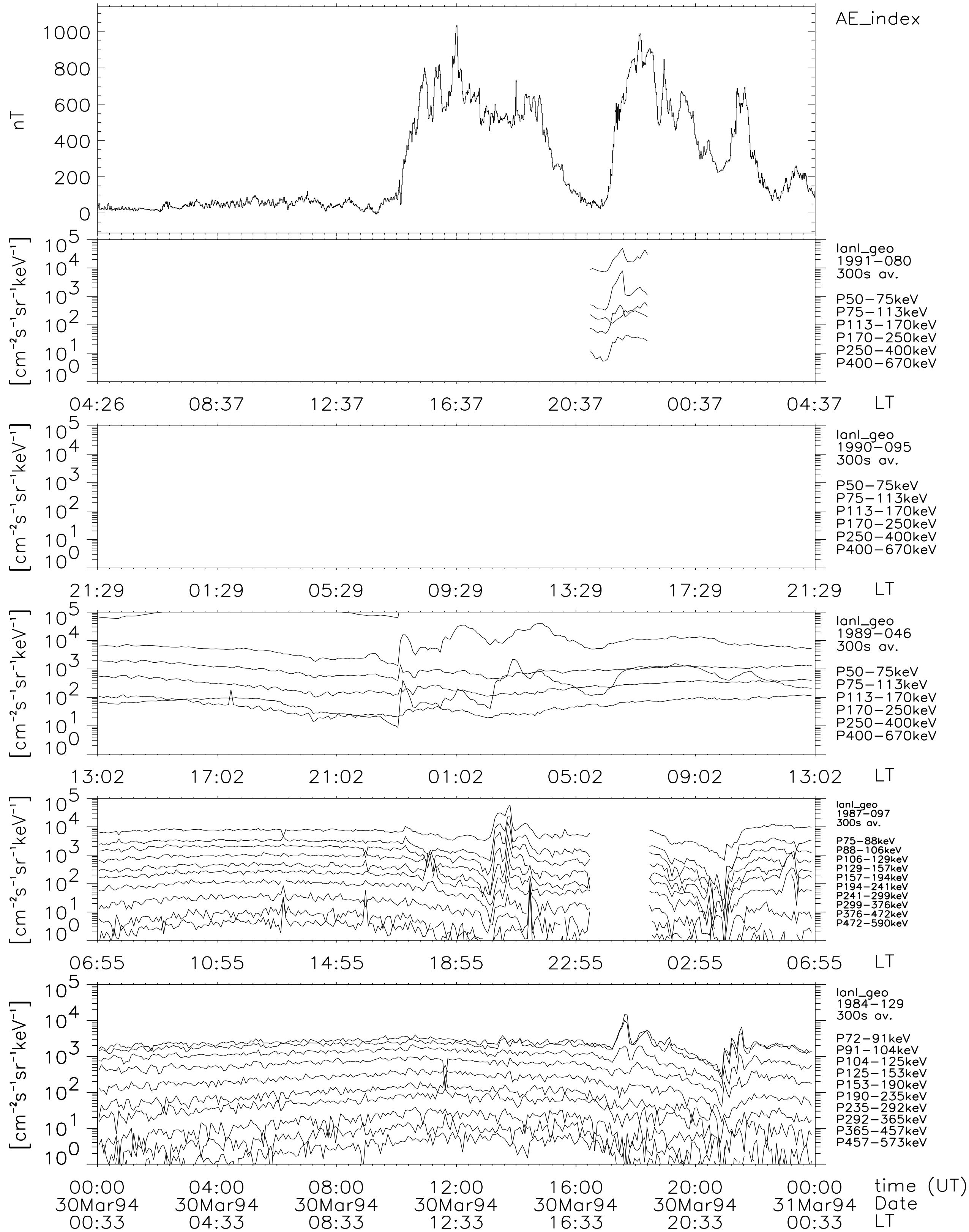
D2 Inside substorm growth region electrons,all geo satellites



D3

Inside substorm growth region ions,all geo satellites



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D4 Inside substorm growth region description

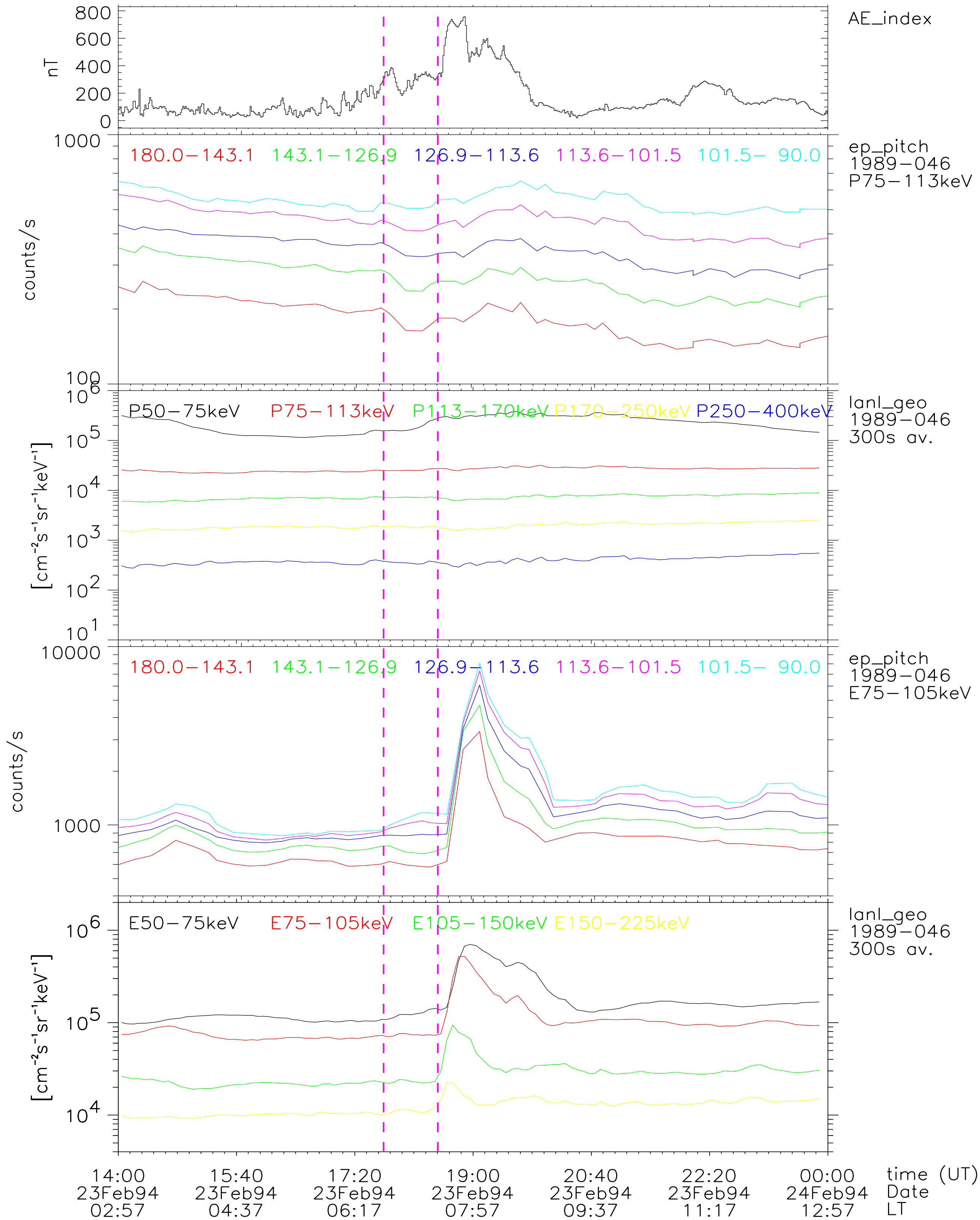
- 1989-046 shows two clear dispersionless injections near midnight corresponding to the first broad peak in AE. The second injection is dispersed.

- 1985-129 on the dayside shows both echoes associated with the dispersionless injections at night. This indicates injection of new populations onto closed drift paths - substorms.

- Electron pitch angle distribution shows classic 90^o midnight dropout which is interrupted by an injection. This completely isotropizes the distribution

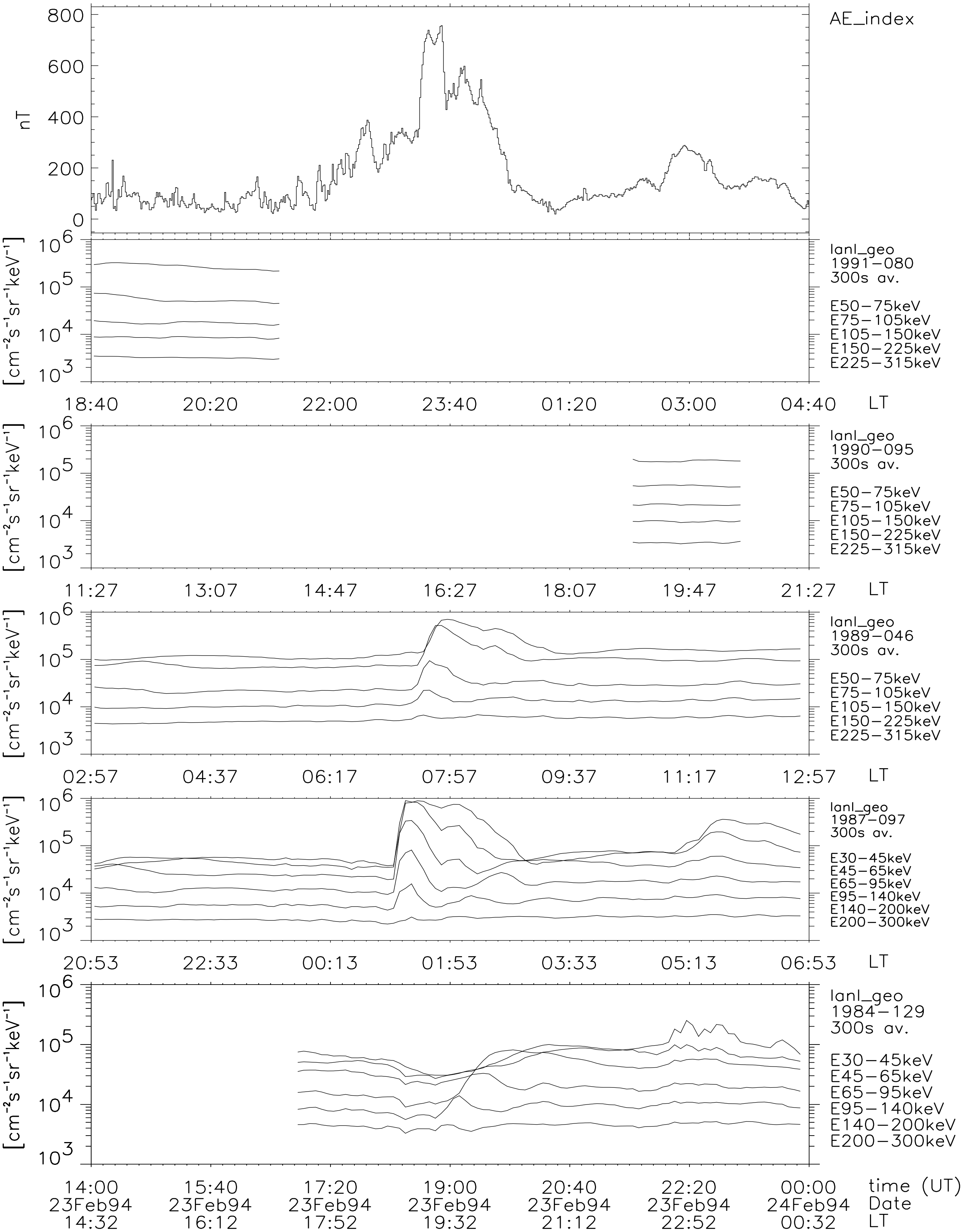
- Ions show similar behavior. Distribution is not isotropic after the first injection. However, the pitch angle determination is based on the electrons, which are isotropic. Out pitch angle determination method fails during such times. Thus all we can say is that the ion distribution is not isotropic.

E1 Outside substorm growth region pitch angle data

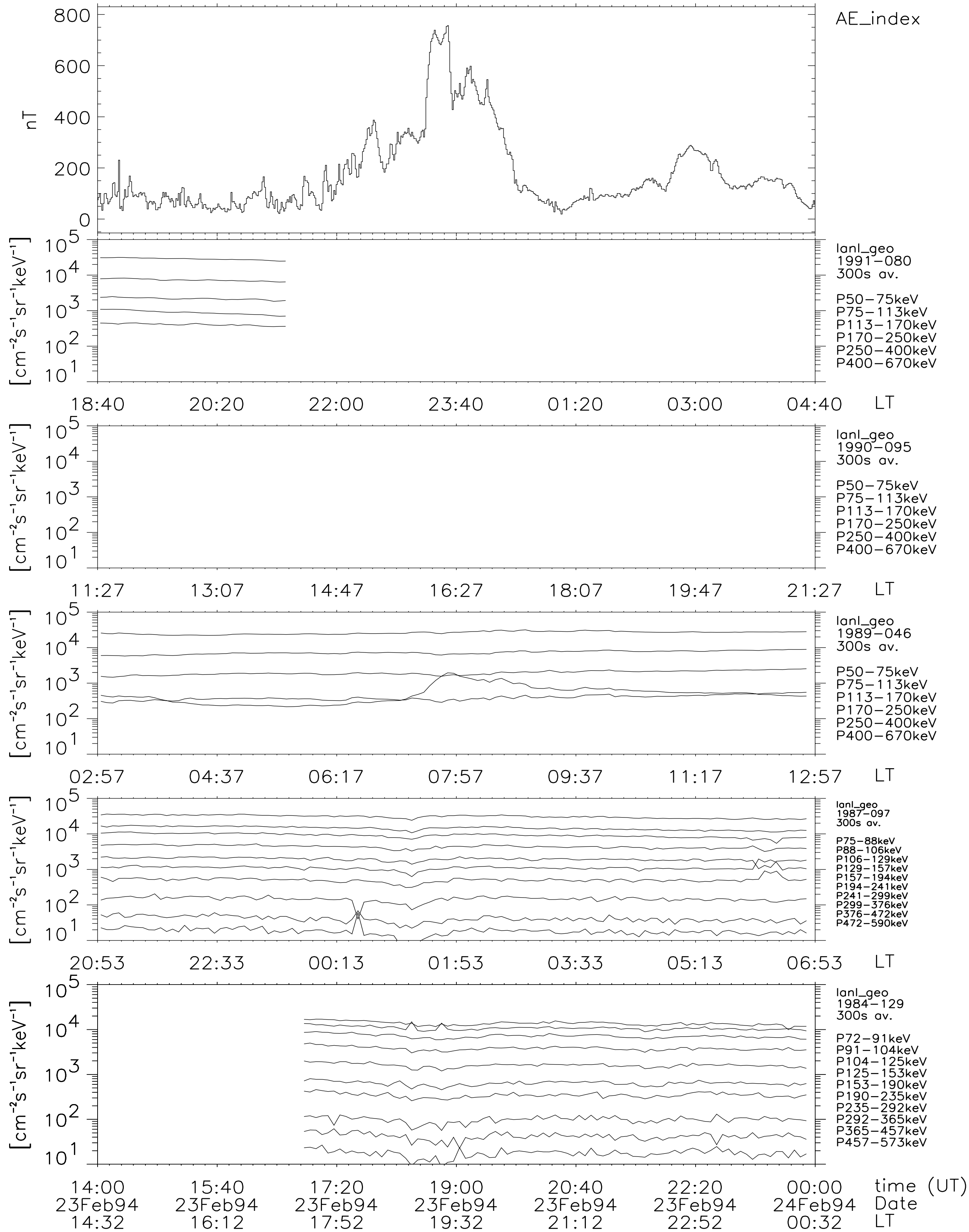


E2

Outside substorm growth region electrons,all geo satellites



E3 Outside substorm growth region ions,all geo satellites



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E4 Outside substorm growth region description

- This is a rare isolated substorm occurring during quiet times. The normal 90^o midnight dropout is absent, indicating that the magnetopause is beyond the 90^o pitch angle drift shell.

- A dispersionless injection is observed by 1987-097 at midnight followed by a dispersed signature at 1989-046 at dawn.

- The period between the dashed vertical lines is part of the growth phase. The electron pitch angles show a small increase for perpendicular electrons.

- the ion pitch angle distribution shows the expected decrease at more field aligned pitch angles. This effect is modest but is preserved even though ions had to drift "the long way around" to get to dawn.

- We interpret this observed decrease in the non 90^o pitch angle particles as scattering loss into the loss cone due to drifting through a stretched substorm growth field topology.

F. Summary

- We have successfully used a method to extract pitch angle information for energetic particle data on a spacecraft with no magnetic field. This method fails when the distribution becomes isotropic.
- We have predicted and observed a change in the pitch angle distribution of energetic ions that drift through a stretched field line topology such as that which occurs during the substrom growth phase.
- The effect has been observable for ions only. Electrons, due to their small gyroradii, remain adiabatic in configurations which already break the adiabatic constants for ions.
- The observed effect is a subtle one and best observed during quiet times and isolated substorms. Other large scale changes of the pitch angle distribution (such as magnetopause shadowing) could often dominate this effect.
- Future work includes detailed particle tracing in model stretched fields. The degree of pitch angle anisotropy observed during the substrom growth phase should yield a handle on the degree of field line stretching occurring near midnight, using energetic particles as remote sensors.